An Efficient Proactive Tree Building Scheme for IEEE 802.11s based Wireless Mesh Networks

Sung-Jun Bae and Young-Bae Ko
Graduate School of Information and communication
Ajou University
Suwon, Republic of Korea
sungjun@uns.ajou.ac.kr, youngko@ajou.ac.kr

Abstract— **The IEEE 802.11s standard (Draft 3.02) defines a path selection algorithm, named HWMP (Hybrid Wireless Mesh Protocol) which combines an on-demand path selection mode with a proactive tree building mode. The proactive tree building mode in HWMP periodically maintains the routing table. Short tree update intervals can improve the accuracy of the routing table, but may cause high overhead due to frequent message transmissions. On the other hand, long update intervals may cause long delays for path recovery in case of link breaks. In this paper, we propose an efficient proactive tree building scheme that adjusts the period of messages transmitted by root mesh node for reducing the overhead. Also, it does not rebuild the whole tree but just modifies the parts of the proactive tree by the *Alternative Parent Node, Local Repair* and *RANN solicitation* to solve the problem of the broken link.**

Keywords: Wireless mesh networks, IEEE 802.11s, Mesh routing protocol

I. INTRODUCTION

The wireless mesh network (WMN) is an emerging technology that supports many important applications such as Internet access, emergency and disaster recovery, security and surveillance, health and medical systems, and public transportation systems. These networking applications can benefit from the WMNs' characteristics such as multi-hop routing, auto-configuration, bandwidth fairness, low cost, easy deployment, self-healing and self-organization [1][2]. The interest in WMNs has increased in recent years, and several international standardization organizations are now developing specifications for wireless mesh networking. The IEEE 802.11 Task Group S (TGs) is standardizing wireless mesh networking based on the IEEE 802.11 WLAN and announced the draft standard version 3.02 on May 2009 [3].

The HWMP is the default path selection protocol in the current draft standard, which consists of two different modes: *On-demand path selection mode* and *Proactive tree building mode*. The proactive tree building mode constructs a tree routing topology by using the proactive PREQ (Path Request) mechanism or the proactive RANN (Root Announcement) mechanism when the root mesh node is configured. The resulting tree path is utilized for a mesh node to communicate with the root mesh node only. However, when a mesh node needs to communicate to any other general mesh nodes, the on-demand path discovery is initiated.

In this paper, we assume the RANN mechanism is utilized to maintain the proactive tree routing path. In the proactive RANN mechanism, the root mesh node periodically broadcasts RANN packets to all mesh nodes in the network in order to refresh the tree routing path. Since this RANN mechanism maintains paths from the root mesh node to every other mesh node in a proactive manner, the actual data communication between them can occur without any additional delay.

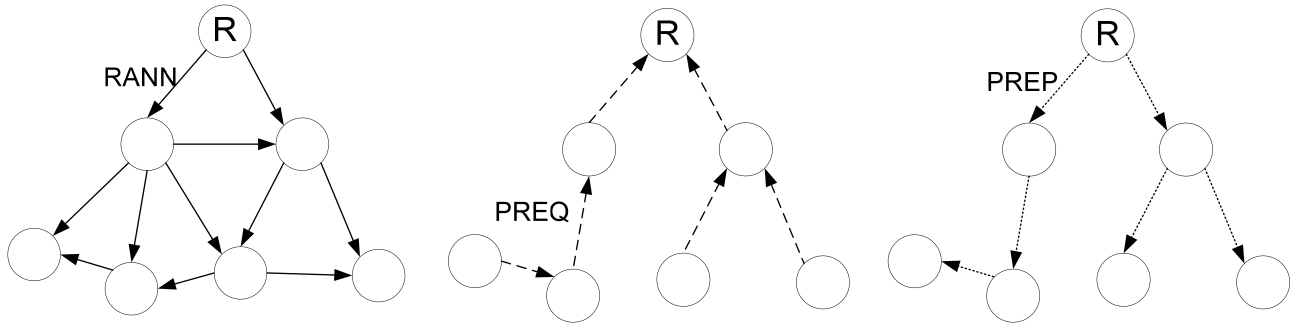
The RANN transmission interval has an effect on the performance of the proactive tree building mode. If the interval is short, the path reliability becomes high, but the maintenance cost increases. On the other hand, if it is long, the maintenance cost decreases, but the delay increases as the on-demand path discovery would be conducted when a link breakage occurs. In this paper, we propose an efficient proactive tree building scheme which provides high reliability with low maintenance cost. The proposed scheme not only tries to keep the interval as long as possible to minimize the maintenance cost but also provides additional mechanisms to improve path reliability even in environments where wireless mesh links are frequently broken.

The remainder of this paper is organized as follows. In Section II, we briefly describe the IEEE 802.11s standard and the HWMP. Section III presents the proposed scheme for efficient proactive tree building. Section IV shows the simulation results of our proposed scheme. Finally, Section V concludes the paper.

II. BACKGROUND: THE IEEE 802.11S STANDARD

The IEEE 802.11s started as a study group for extended service set (ESS) mesh networking of the IEEE 802.11. After becoming the task group in July 2004, the IEEE 802.11s started the standardization, and recently, the standardization

This research was supported by the MKE(The Ministry of Knowledge Economy), Korea, under the ITRC(Information Technology Research Center) support program supervised by the IITA(Institute for Information Technology Advancement)" (IITA-2009-C1090-0902-0003) and by the Korea Science and Engineering Foundation (KOSEF) grant funded by the Korea government (MEST: Ministry of Education Science and Technology) (No. 2009-0072709)



(a) Root broadcasts a RANN (b) Backward Path update by the unicast PREQ (c) Forward Path update by the unicast PREP

Figure 1. Proactive RANN mechanism

has almost come to the end. The 802.11s standard defines the architecture of WMNs. A mesh portal acts as a gateway or a bridge that connects the internal mesh network to other exterior IEEE 802 LAN segments. A mesh station supports mesh service and participates in the interoperable formation and operation of the mesh network, such as path selection and data forwarding. A mesh access point provides the mesh functionalities and also the AP functionalities simultaneously.

The IEEE 802.11s standard defines a default path selection protocol called hybrid wireless mesh protocol, which uses the airtime link metric as the default link metric. The airtime link metric may be used by a path selection protocol to identify an efficient radio-aware path. This metric reflects both the transmission bit rate and error rate. HWMP supports two modes, on-demand mode and proactive tree building mode. The functionality of on-demand mode is always available whether the root mesh station is configured or not. It allows mesh stations to communicate by using peer-to-peer paths. Proactive tree building mode can be performed by configuring a mesh station as the root mesh station and using either the proactive PREQ or RANN mechanism.

On-demand path selection mode is based on rules and primitives derived from Ad Hoc On-Demand Distance Vector (AODV) protocol and modified for MAC address-based path selection and link metric awareness. This mode is used when a source mesh node needs to find a path to a destination mesh station. A source mesh node broadcasts a PREQ message with the destination and link metric. Upon receiving the PREQ message, mesh nodes update the path to the source node if sequence number is greater or the sequence number is the same and offers a better metric. After creating or updating a path to the originator, the target mesh node transmits a unicast PREP (Path Reply) back to the originator mesh node. When the source mesh node receives the PREP message, it creates a path to the destination. From this mechanism, a bidirectional, best metric end-to-end path is established between the originator and target mesh node.

In the proactive RANN mechanism, as shown in Fig. 1, the root mesh node periodically broadcasts a RANN message to all mesh nodes in the network in order to refresh the tree routing path. The information contained in the RANN is used to disseminate path metrics to the root mesh node. Upon receiving a RANN message, nodes transmit a unicast PREQ message toward the reverse path of the RANN message to create or update the path to the root mesh node. The message will be treated if the RANN message contains a greater sequence number, or the sequence number is the same and the RANN offers a better metric than the current path. When a root mesh node receives a PREQ message, it sends back a PREP message to establish a bidirectional path. The unicast PREQ message creates the reverse path from the root mesh node to the originator mesh node, while the PREP message creates the forward path from the mesh node to the root mesh node.

III. Proposed Scheme

The main purpose of the proposed scheme is to reduce the maintenance cost of the proactive tree and path recovery delay when a link is broken. Our scheme is based on the current draft standard with only minimum modification. When a mesh node detects a broken link towards the root mesh node, it initiates the recovery process to reconstruct the path. A broken link is detected by the missing ACK packet when a unicast transmission is failed. The proposed recovery process has three phases as follows: The first phase is *utilizing the alternative parent node* and, the second phase is *local repair*. The final phase is *utilizing RANN solicitation* to rebuild the entire routing tree. Each phase is executed in a step by step manner, so the next phase proceeds only if the previous step fails to recovery the path.

A. The 1st Phase: Utilizing Alternative Parent Node

When a mesh node receives multiple RANN messages, the HWMP algorithm selects a parent node which has the smallest airtime link metric to construct a path towards the root mesh node. We define the alternative parent node which has the second smallest airtime link metric, and each node stores the MAC address of the alternative parent node. When the link for the parent node is broken, a mesh node can reconstruct the path by utilizing the alternative parent node as the new parent. To do this, the mesh node first sends a unicast PREQ message to the alternative parent node. Since the final destination of this PREQ message is the root mesh node, the alternative parent node forwards the received PREQ to the next hop towards the root mesh node. Upon receiving the PREQ message, the intermediate nodes create or update the backward path. Finally, the root mesh node updates the path information to the PREQ initiator node and it sends back the PREP message. It completes updating of the bidirectional path.

Fig. 2 shows an example of the first phase. R-A-C-G is the initial path between node G and root R, D is the alternative parent node of G. When the link between C and G is broken, G changes its parent from C to D and transmits a unicast PREQ message to D. Upon receiving the PREQ message, node D, B and R update their routing table towards G. Then root node R transmits the PREP message. This PREP message is forwarded up to G. As a result, the path is changed to R-B-D-G.

If the path cost of the alternative parent is too high, performance might degrade. To solve this problem, we define parameter α and a node selects its alternative parent only if the airtime link metric is smaller than the smallest airtime link metric×α. The high α value increases the possibility to produce an inefficient path having high path cost while the small α value make it hard to get an alternative parent. Therefore determination of the appropriate α value is important for performance. We have experimented with various values in the simulation study and utilize a best value for the performance evaluation.

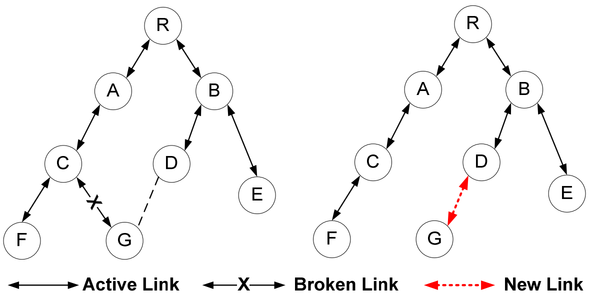


Figure 2. Examples of the first phase – Alternative parent node

B. The 2nd Phase: Local Repair

If a node does not have the alternative parent node or path recovery in the first phase fails, the second phase algorithm is executed. This algorithm tries to repair the routing tree by locally discovering another path to the unreachable mesh node. The basic idea behind this scheme is that the parent node is placed in the closer location than the root node. Therefore we assume the path recovery time for the parent node would be shorter than the recovery time for the root node. We perform this local repair algorithm without any amendment to the current IEEE 802.11s draft. We utilize several fields in the PREQ message which are already defined in the standard as follows.

- The TTL is the maximum transmission hop count.
- The *Per Target Flag* of the PREQ message decides action of the intermediate mesh node which receives this message.
- If the *Target Only (TO)* is zero, the intermediate mesh nodes that have the path can transmit the PREP message. However, if TO=1, only the target mesh node transmits the PREP.
- The *Reply and Forward (RF)* controls the PREQ message transmission of the intermediate mesh nodes. If TO=0 and RF=0, the PREQ message is not forwarded. If RF=1, the PREQ message is forwarded. When TO=1, RF has no effect.

In order to initiate the local repair process, a mesh node broadcasts the PREQ message. We set TTL to β so that the PREQ message is not propagated to the whole network but limited within the restricted area. Therefore β represents the maximum number of hops which can be used for the local repair. The destination address of the PREQ message is configured as the unreachable mesh node. TO and RF flags are configured as 0 so that any intermediate node which has the path to the unreachable mesh node sends back PREP message and the PREQ message is not forwarded more. We can utilize a small β value enough to cover the local area. Therefore the control message overhead reduces while recovery delay decreases.

As shown in Fig. 3, when two paths R-A-C-F and R-A-C-G are established, the link between A and C is assumed to be broken. Detecting a broken link, C tries to recover a path to A. Here, C does not have the alternative parent node, so it fails to recover the path in the first phase. Starting the second phase, C broadcasts PREQ message with TTL=β, destination address=A, TO=0, and RF=0. When the neighboring node D receives this message, it rebroadcasts the message. This message eventually arrives at A. A sends back a unicast PREP message to D. This PREP is delivered to C. As a result, C updates its routing table so that R-A-C-F path is changed to R-A-D-C-F, and R-A-C-G path is changed to R-A-D-C-G.

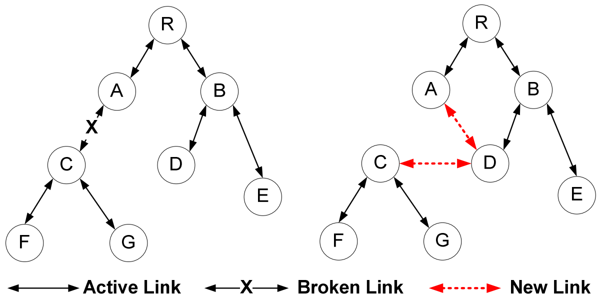
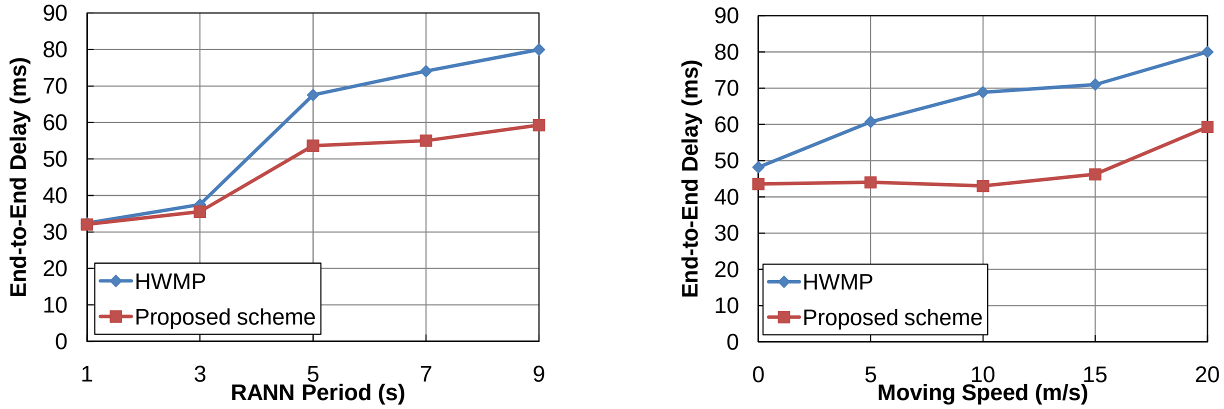


Figure 3. Examples of the second phase – Local Repair

C. The 3rd Phase: Utilizing RANN solicitation

If the previous two phases fail, the entire proactive tree should be rebuilt. The second phase fails when there is no other path within β hop range. In this case, we generate the PERR (Path Error) message for the root mesh node to immediately rebuild the routing tree. Originally, the PERR message is used for announcing a broken link to all destinations in the active paths which includes this broken link. The destination address (DA) field in the PERR means the address of the unreachable mesh node. In our proposed scheme, the node which finds out a broken link generates a PERR message, and the DA field is the root mesh node for



(a) (b)

Figure 4. Comparison of Average End-to-End Delay

the RANN solicitation. The mesh node which receives the PERR message forwards this message up to the root mesh node without any additional operation. When the root mesh node receives this PERR message, it immediately broadcasts a RANN message to rebuild the entire proactive routing tree.

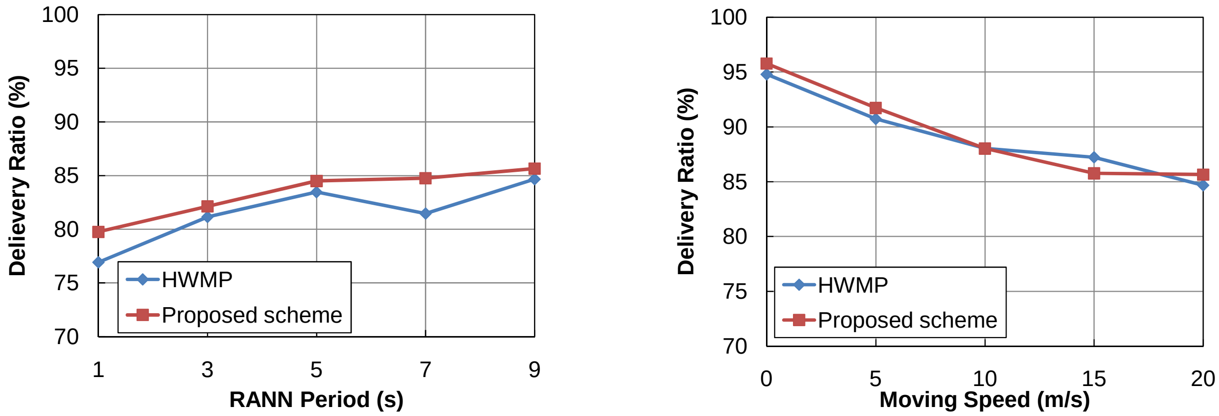
IV. PERFOMANCE EVALUATION

For performance evaluation, we performed simulations by using Qualnet 4.5. The simulation was conducted on a 1000m×1000m area with 30 mesh nodes which are randomly deployed. Each node has the transmission range of 250m. The simulation was run ten times with each simulation having different random seed numbers and the duration lasting 100 seconds. Link speed is set to 11Mbps.

In order to analyze data transmission in environments where frequent link breaks occur, we customized an environment where one third of the mesh nodes move according to a random waypoint mobility model [9]. In order to verify the proactive tree path, one fifth of the mesh nodes transmit 512 bytes CBR packets to the root mesh node. The α and β parameters affect on the delay and overhead, because a small value of α may cause delay and a large value of β may increase overhead. We choose 2 for both α and β, since this value shows the best performance among various tested values.

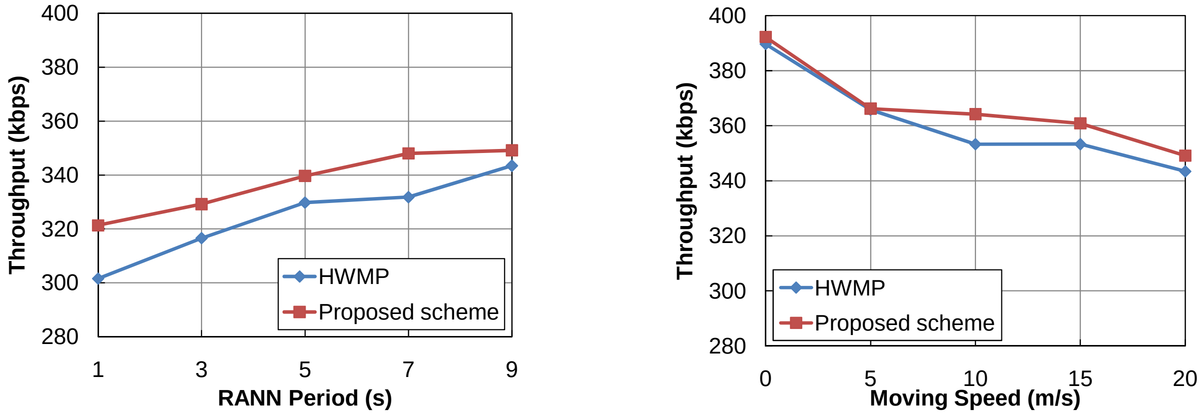
Two types of scenarios were simulated. The first scenario changes the RANN interval from a default value of 1 second [3] to 9 seconds with a difference of 2 seconds. The max speed of mobile nodes was fixed as 20m/s. The second scenario modifies the root mesh node to periodically broadcast the RANN message every 9 seconds and the maximum speed of moving nodes was changed from 0 to 20m/s with a difference of 5m/s. We made our performance evaluation on three factors, which are average end-to-end delay, data packet delivery ratio, and average throughput. End-to-end delay is the time from the transmission of the packet from the source node until the reception of the packet by the destination node. Delivery ratio is successful delivery ratio of the data packet to root mesh node. Throughput represents the average rate of successful data packet delivery per second.

In HWMP, the reliability of the proactive tree decreases as the RANN interval increases. As a result, when broken links occur, the source mesh node discovers a path to the root



(a) (b)

Figure 5. Comparison of Delivery ratio



(a) (b)

Figure 6. Comparison of Average Throughput

mesh node by using the on-demand mode. This may cause considerable delay. Furthermore the probability of broken link occurrence increases as the max speed of moving node increases. This brings out the same results as discovering a path in the on-demand mode. However, the proposed scheme allows the use of recovered proactive tree, so the average end-to-end delay is reduced. We achieved similar results from two scenarios, which the delay is reduced by maximum of 37.5%, with an average of 30%, as shown in Fig. 4.

Short RANN period generates many control messages in the network including additional messages for discovering the path in the on-demand mode. Therefore, as shown in Fig.5 (a), the delivery ratio increases when the RANN interval increases. As shown in Fig.5 (b), the links are more frequently broken as the max speed of moving node increases, so delivery ratio decreases. For both scenarios, the proposed scheme provides slightly higher success in delivery compared to the HWMP. The throughput graph shows similar results to the delivery ratio graph. As the RANN period increases, the transmission of control message decreases. This leads to the decrease of the packet collision and network overhead, which results in increased throughput. Fig. 6 shows that the proposed scheme represents higher throughput due to the increase of the successful transmission ratio and decrease of delay.

In overall, we can conclude from the graphs that the proposed scheme had better performance than the HWMP. That is, the proposed scheme not only transmits the data successfully but also guarantees higher throughput.

V. CONCLUSION

In this paper, we propose an efficient proactive tree building scheme to reduce periodic path maintenance cost and path recovery delay. Simulation results have shown advantages of the proposed scheme with higher data delivery success ratio and throughput. Also, the end-to-end delay is decreased in spite of the increased RANN interval. However, additional research such as performing mathematical analysis to configure α for alternative parent node needs to be done. Future work would include the performance evaluation result in actual mesh network testbeds based on real environments.

REFERENCES

[1] M.-J. Lee, J. Zheng, Y.-B. Ko, and D.M. Shrestha "Emerging standards for wireless mesh technology," IEEE Wireless Comm., Apr. 2006.

[2] Ian Akyildiz, Xudong Wang, and Weilin Wang, "Wireless Mesh Networks: A Survey," Elsevier Computer Networks, March 2005.

[3] IEEE P802.11s™/D3.02 , Draft amendment to standard IEEE 802.11™: ESS Mesh Networking. IEEE, May. 2009, work in progress.

[4] Xudong Wang and Azman O.Lim, "IEEE 802.11s wireless mesh networks: Framework and challenges," in ELSEVIER Ad Hoc Networks volume 6, No. 6, pp.970-984, 2008

[5] Michael Bahr, "Proposed Routing for IEEE 802.11s WLAN Mesh Networks," WICON'06, The 2nd Annual International Wireless Internet Conference, August 2006.

[6] Rosario G. Garroppo, Stefano Giordano, Davide Iacono and Luca Tavanti, "On the development of a IEEE 802.11s Mesh Point prototype," Tridentcom 2008, March 2008.

[7] Andreas M¨uller, "Meshed Wireless Networks", Seminar Mobil Communications SS 2006.

[8] Perkins, C. E., Belding-Royer, E. M., and Das, S. R. Ad hoc On-Demand Distance Vector (AODV) Routing. IETF Experimental RFC 3561, July 2003.

[9] F. Bai, A. Helmy, "A Survey of Mobility Modeling and Analysis in Wireless Ad Hoc Networks", Book chapter in Wireless Ad Hoc and Sensor Networks, Kluwer academic Publishers, June 2004.

[10] QualNet Simulator version 4.5, Scalable Network Technologies, www.scalable-networks.com